

CLOUDS OVER THE EQUATORIAL AND TROPICAL PACIFIC AN INVESTIGATION BASED ON TIROS SATELLITE AND JET AIRCRAFT OBSERVATIONS

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ABSTRACT

A series of 35-mm. color slides and 16-mm. motion pictures of clouds were taken from a jet aircraft flying at about 30,000 ft. The aircraft flew from Honolulu to Papeete to Los Angeles and returned to Honolulu, twice crossing the equator. TIROS satellites IX and X were programmed to take a maximum number of cloud pictures along the path of the aircraft when it was in flight.

Corresponding pictures from the jet aircraft and TIROS are compared and related to the synoptic features at the surface and aloft. Cloud types, distribution, and organization over the eastern tropical Pacific Ocean are discussed.

1. INTRODUCTION

In January 1966 an opportunity arose for one of the authors to travel by jet aircraft from Honolulu to Papeete to Los Angeles and return to Honolulu. The first two legs of the flight were unusual in that they involved both a southbound and a northbound crossing of the equator and were over areas from which very few surface or upper-air observations are available. It was decided, therefore, to take cloud pictures from the aircraft and to try to correlate them with TIROS satellite cloud photographs and also with the synoptic situation at the surface and aloft.

The National Environmental Satellite Center arranged to program TIROS IX and TIROS X to take a maximum number of cloud photographs over the path of the aircraft while it was in flight. TIROS photographs, 106 color 35-mm. slides, 100 ft. of 16-mm. color motion pictures, standard meteorological aircraft observations, and conventional surface and upper-air meteorological reports form the basic raw material of this report. The slides were taken at 10-min. intervals—more frequently when the scene was changing rapidly. The motion pictures were taken in short "bursts," also at 10-min. intervals. The surface and upper-air analyses shown are the operational analyses of the Weather Bureau Forecast Center at Honolulu.

There have been only a few previous cloud investigations using photographs taken at about the same time from research or commercial aircraft and TIROS satellites. In 1964 Honodel [1] made a TIROS-jet aircraft cloud study along a track from Los Angeles to Honolulu. Zipser and La Seur [2] used TIROS and aircraft photographs to study the distribution and depth of convective clouds over the tropical Atlantic Ocean. Johnson and Fett [3] explored clouds over the tropical Atlantic with TIROS and research aircraft. Lessman [4] used TIROS and jet aircraft pictures to study the clouds of the Pacific inter-tropical convergence zone. McClain and Whitney [3] made an aircraft-satellite study of a U.S. east coast cyclone.

TIROS photographs and nephel analyses are used in pilot briefing to help describe the current synoptic situation. TIROS satellites, however, look down at clouds from about 500 mi. above sea level while jet aircraft crews see clouds from about 6 mi. up. Two orders of magnitude separate the heights of the observing platforms. Aircraft crews see mesoscale and microscale features of clouds systems; TIROS satellites record synoptic and mesoscale features. One of the objectives of this study was to learn if larger scale TIROS cloud photographs could be used more effectively as a pilot briefing tool.

2. FLIGHT FROM HONOLULU TO PAPEETE

SYNOPTIC FEATURES

At 0113 GMT January 11, 1966, our jet aircraft departed Honolulu, headed southward, and arrived at Papeete, Tahiti, 5 hr. later. The synoptic situation was not much different from normal. The 0000 GMT January 11 surface chart is shown in figure 1. It is easy to identify the subtropical ridges, the trade winds of both hemispheres, the intertropical convergence zone (ITC) and the equatorial trough.

At 250 mb., figure 2, the trough-ridge pattern, especially in the Northern Hemisphere, departs markedly from the normal westerly pattern.

PHOTOGRAPHS FROM AIRCRAFT

The numbers along a line from Honolulu to Papeete in figures 1 and 2 represent the points where the photographs displayed in figure 3 were taken from the jet aircraft. Pictures were taken looking toward the ENE, perpendicular to the flight path. The first three pictures, snapped within the first hour aloft, show a few stunted cumulus clouds but mostly thin stratiform clouds, probably stratocumulus. The clouds are not those of "typical" trade wind cumulus of fine weather. Picture 4 shows a more typical scene. Stratiform clouds, however, soon became the dominant feature again (pictures 5 and 6).

The only available raobs (not reproduced) that may help to interpret these pictures are those near the beginning of the flight in the Hawaiian Islands. They show a fairly moist layer with steep lapse rate in the lowest 5,000 ft. topped by a very stable dry layer about 5,000 ft. thick. Convective activity was apparently too weak to penetrate the stable layer. The cloud thickness is estimated to be about 2,000 ft. The absence of high and middle clouds suggests a general subsidence aloft, and this seems to be borne out by the large temperature-dew point spreads in the upper-air soundings and the anticyclonic flow at 250 mb.

The scene changed considerably near 8°N. The aircraft was now flying between layers with a thick cirrostratus overcast and a stratiform undercast. The entry made in our notebook near 7°N. read, "Towering cumulus ahead. ITC? Slight turbulence." The aircraft penetrated the intertropical convergence zone (ITC) near 6°N. and emerged near 2°N. As luck would have it, a new roll of film was imperfectly inserted into the still camera just at this time and so the 35-mm. slides were lost. Pictures 7, 8, and 9 (fig. 3) were made from the movie and are not very sharp. Picture 7, taken at the edge of the ITC, shows a cirrostratus overcast and an undercast consisting of 6/8 stratiform and 2/8 towering cumulus with tops estimated about 15,000 to 20,000 ft. above sea level.

For the next 100 mi. the aircraft flew in and out of the cirrostratus deck, the top of which was near flight level, 33,000 ft. Then picture 8 was taken. Cirrostratus overcast persisted but the lower layer of 3/8 stratiform and 2/8

cumulus gave evidence of suppressed convective activity. Picture 9 was taken near the southern boundary of the ITC but it is not clear what one sees. Our notes read, "Altostratus above stratus? Altostratus appears to be near flight level." This brings up a problem in connection with observing clouds from the ground and from aloft. Most meteorologists have had training and experience in observing and classifying cloud types from the ground, but only limited observational experience from aircraft. We, also, have had very little experience viewing and identifying clouds from above. And so it may be that what was described as altostratus in picture 9 may have been the top of cumulonimbus.

At 1.5°N. there was a sharp clearing, the cirrostratus layer became thin and broken and small cumulus clouds covered only 1/8 the field of view.

The notes on picture 10, at the equator, say, "thin cirrus, 3/8; small cumulus, 3/8; rows lined up ESE to WNW."

Organization of clouds into rows on a mesoscale is not a new observation. It was observed again on the north-bound crossing of the equator. Kuettner [6] found it to occur from the Tropics to as far north as the Arctic. He stated that, "... most cloud bands line up in the direction of flow and originate in convective layers. The characteristic wind profile in the vertical has a jet-like curvature." Malkus and Riehl [7] also state that in the Tropics "the common mode of organization is parallel to the low level flow." We did not have sufficient information to check these statements.

Kuettner and Soule [8] assert that, "Cloud streets are common also in the equatorial zone." Except for the picture they show, we know of no other observations of this phenomenon at the equator.

By the time the aircraft reached 5°S. and picture 11 was taken the sun was setting. The record states, "Few Ci; Cu 3/8."

TIROS X PHOTOGRAPHS

Figure 4 is the TIROS X cloud mosaic for 2128 GMT January 10, 1966. Its nephanalysis is plotted on the surface chart (fig. 1). The satellite pictures were taken about 4 hr. before the jet aircraft departed Honolulu. Since the synoptic situation was changing slowly the differences between the corresponding views from the aircraft and TIROS X may be expected to be small.

Near spots 1, 2, and 3 on the mosaic and nephanalysis one might expect to find fair weather cumulus but the corresponding aircraft pictures (1, 2, 3 of fig. 3) show that stratiform clouds dominate the field of view. While the mosaic is marred by electronic interference, it would be difficult to construct a scene like that of aircraft picture 4 from examination of the corresponding TIROS view. There is a chance that one might be able to discern lower clouds beneath the hazy veil near point 6, but the nephanalyst was not able to do so (see fig. 1). At points 7, 8, and 9 one might expect from the cloud brightness as well as from examination of other TIROS photographs of this area the

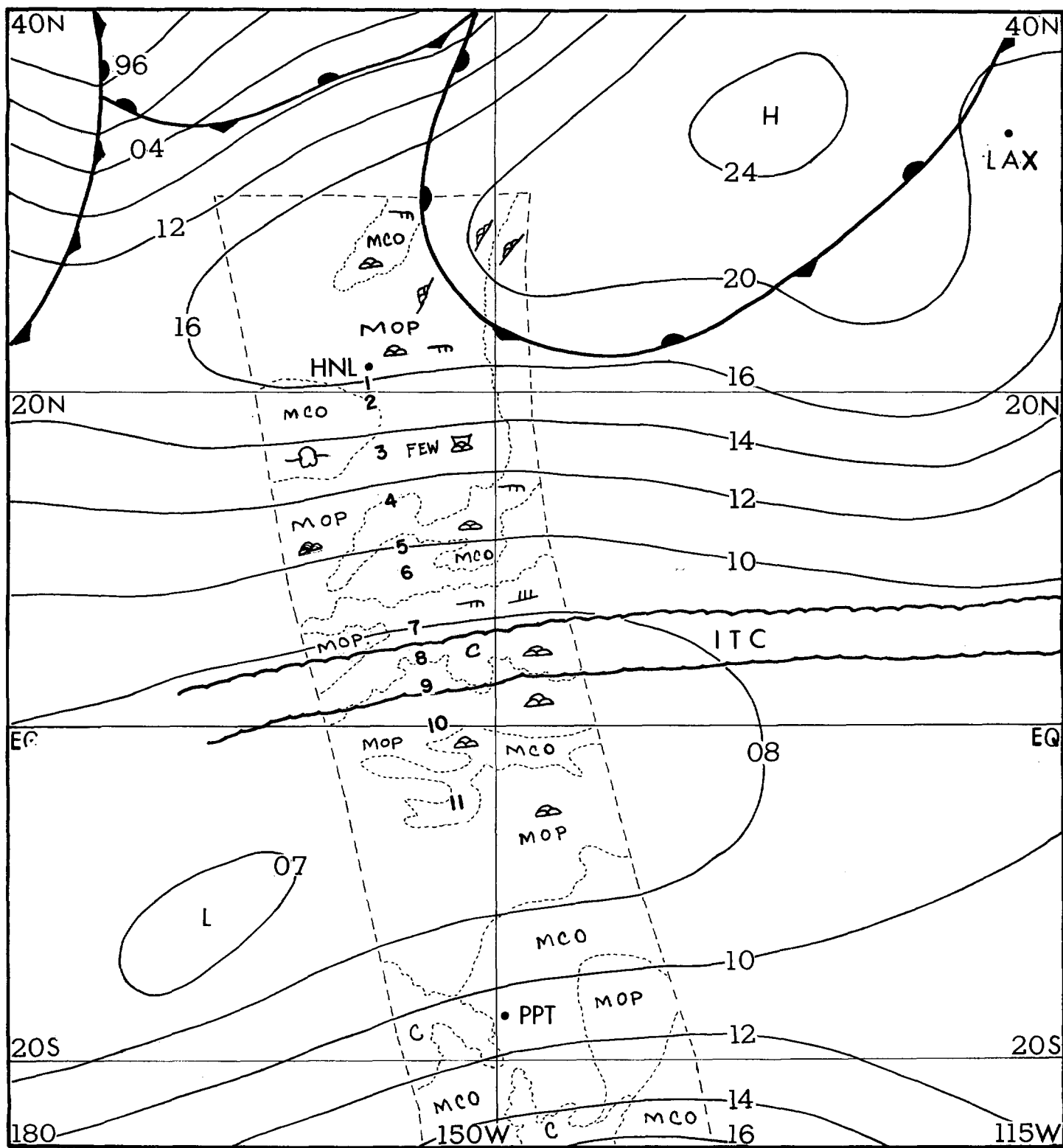


FIGURE 1.—The surface synoptic chart for 0000 GMT January 11, 1966. Isobars are labelled in millibars above 1,000. The intertropical convergence zone is marked ITC. The nephanalyses are those corresponding to the TIROS mosaics of figure 4. The small numbers along a line from Honolulu (HNL) to Papeete (PPT) correspond to the numbers on the cloud mosaics of figure 4 and to the numbered pictures of figure 3.

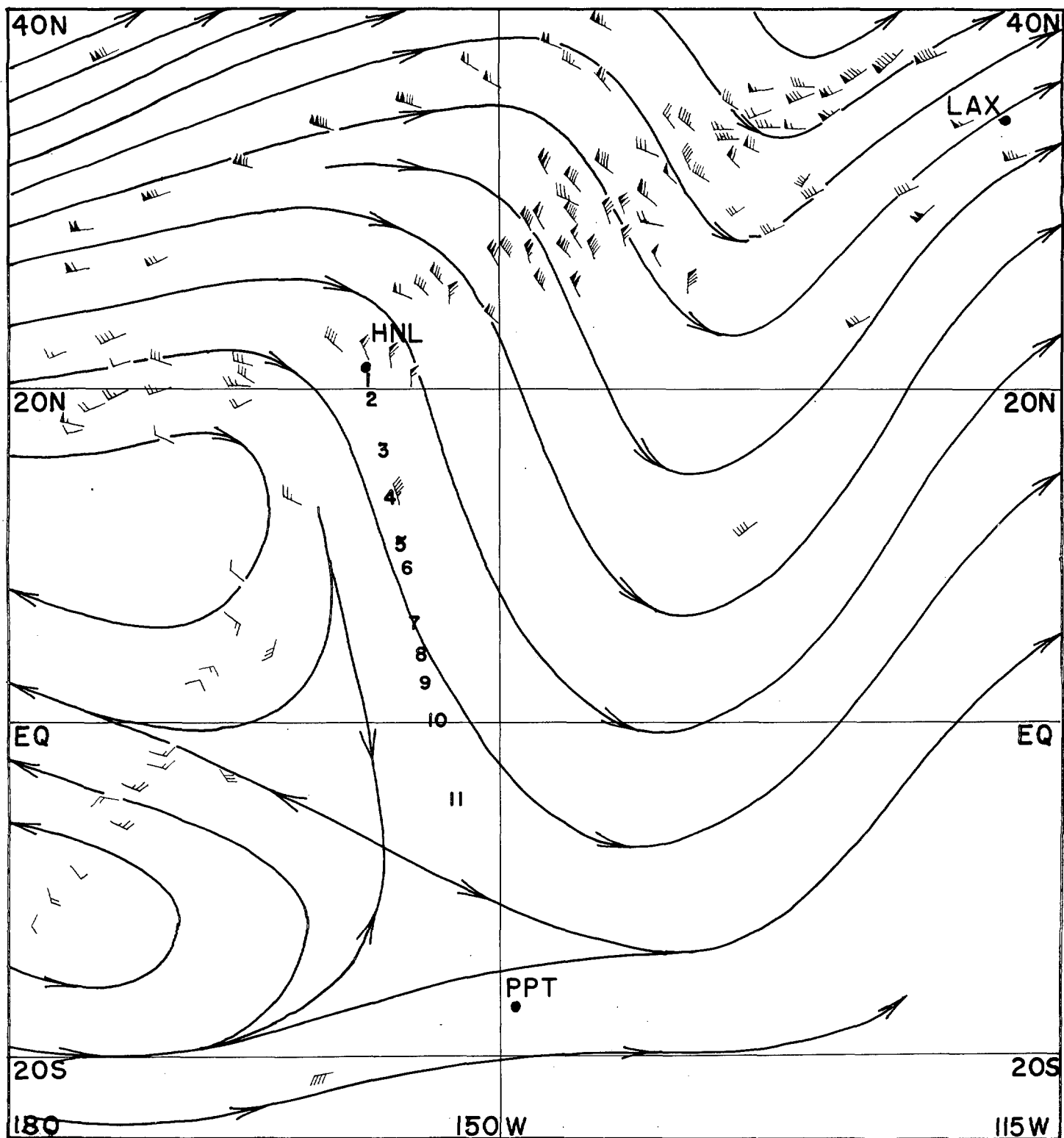


FIGURE 2.—The 250-mb. streamline chart for 0000 GMT January 11, 1966. The plotted winds at raob stations are for 250 mb. Most winds are from aircraft observations which range in height from 28,000 to 40,000 ft. and range in time for ± 9 hr. of map time.

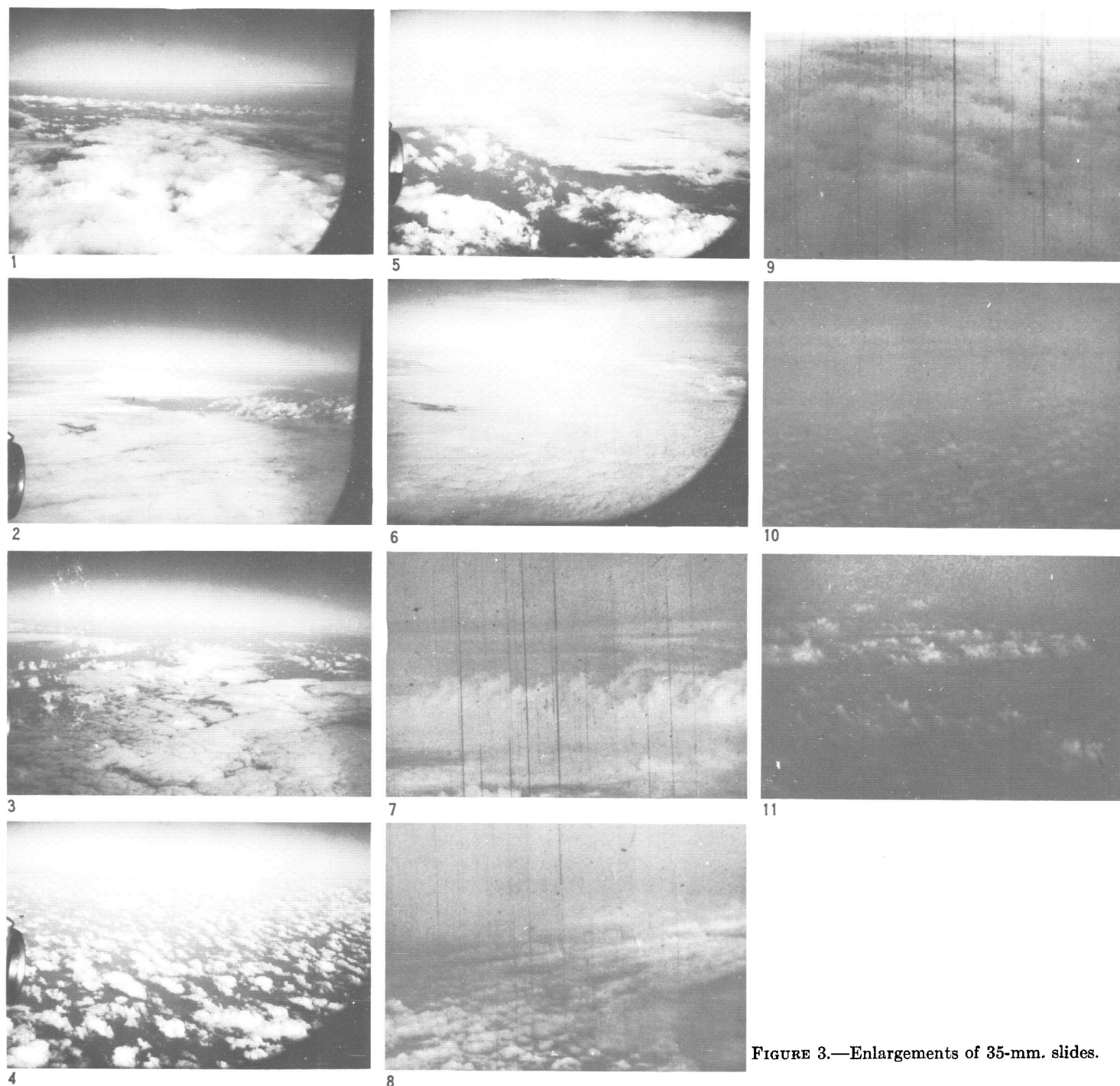


FIGURE 3.—Enlargements of 35-mm. slides.

strong convective activity actually pictured in the aircraft views. One might also expect scenes like those of pictures 10 and 11 to be observed at the corresponding spots on the mosaic.

The lack of correspondence between some of the TIROS and aircraft views may be due to the 4- to 6-hr. time difference between them. It may also be that the differences between cumulus and stratocumulus clouds are not always sufficiently large to be brought out by differences in brightness, organization, and texture as observed by TIROS X. Ground-based observers are sometimes hardpressed to distinguish between cumulus and stratocumulus.

3. FLIGHT FROM PAPEETE TO LOS ANGELES

SYNOPTIC SITUATION

At 2003 GMT January 12, 1966, our jet aircraft departed Papeete on the second leg of the flight; 8 hr. later it landed in Los Angeles. The first quarter of the leg was at 33,000 ft.; the second quarter at 35,000 ft.; the last half at 37,000 ft. The surface synoptic situation for 0000 GMT January 13 is shown in figure 5. While frontal systems in the north Pacific moved rapidly eastward, little change took place in the Tropics in the 48 hr. between the times of figures 1 and 5.

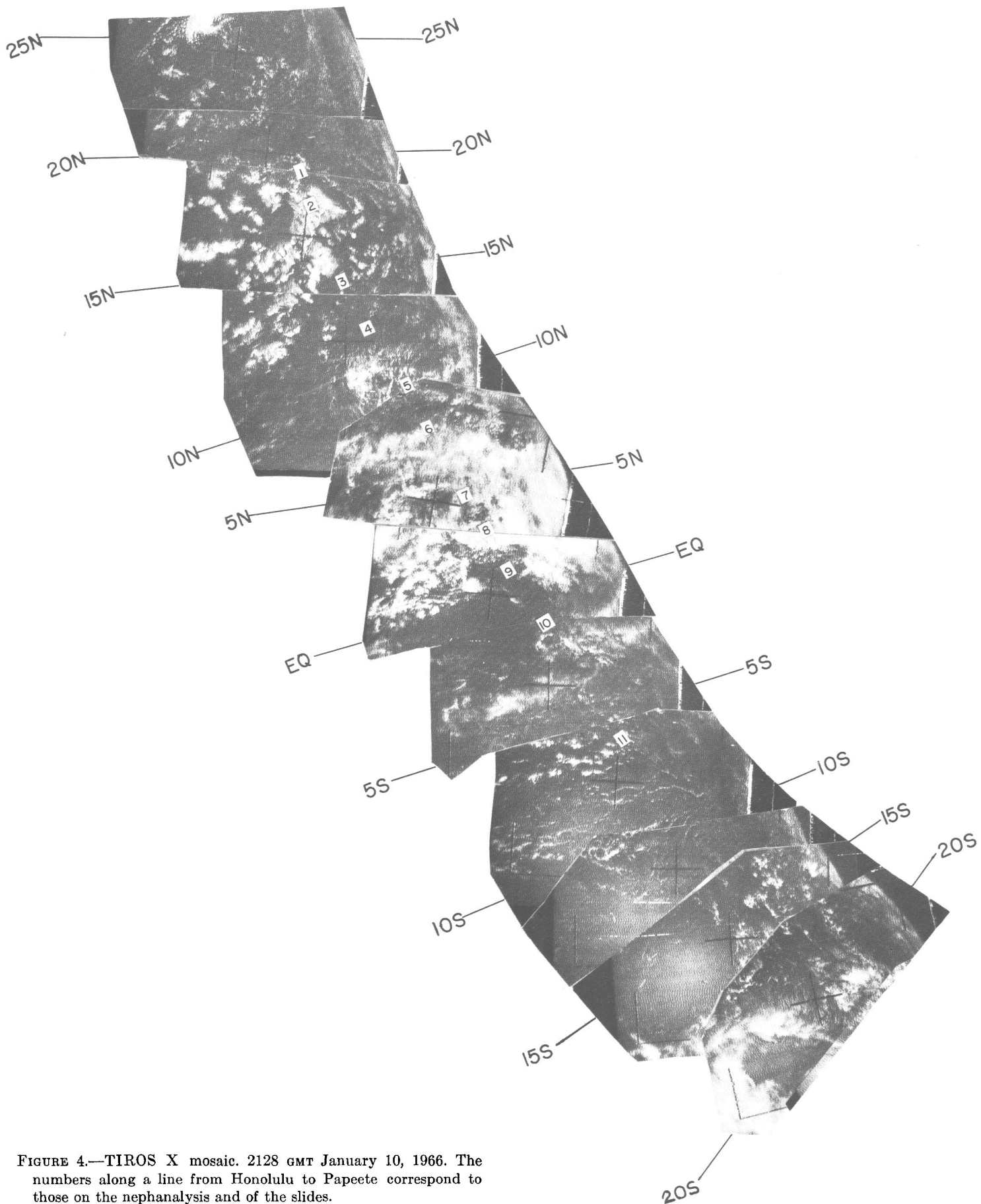


FIGURE 4.—TIROS X mosaic. 2128 GMT January 10, 1966. The numbers along a line from Honolulu to Papeete correspond to those on the nephanalysis and of the slides.

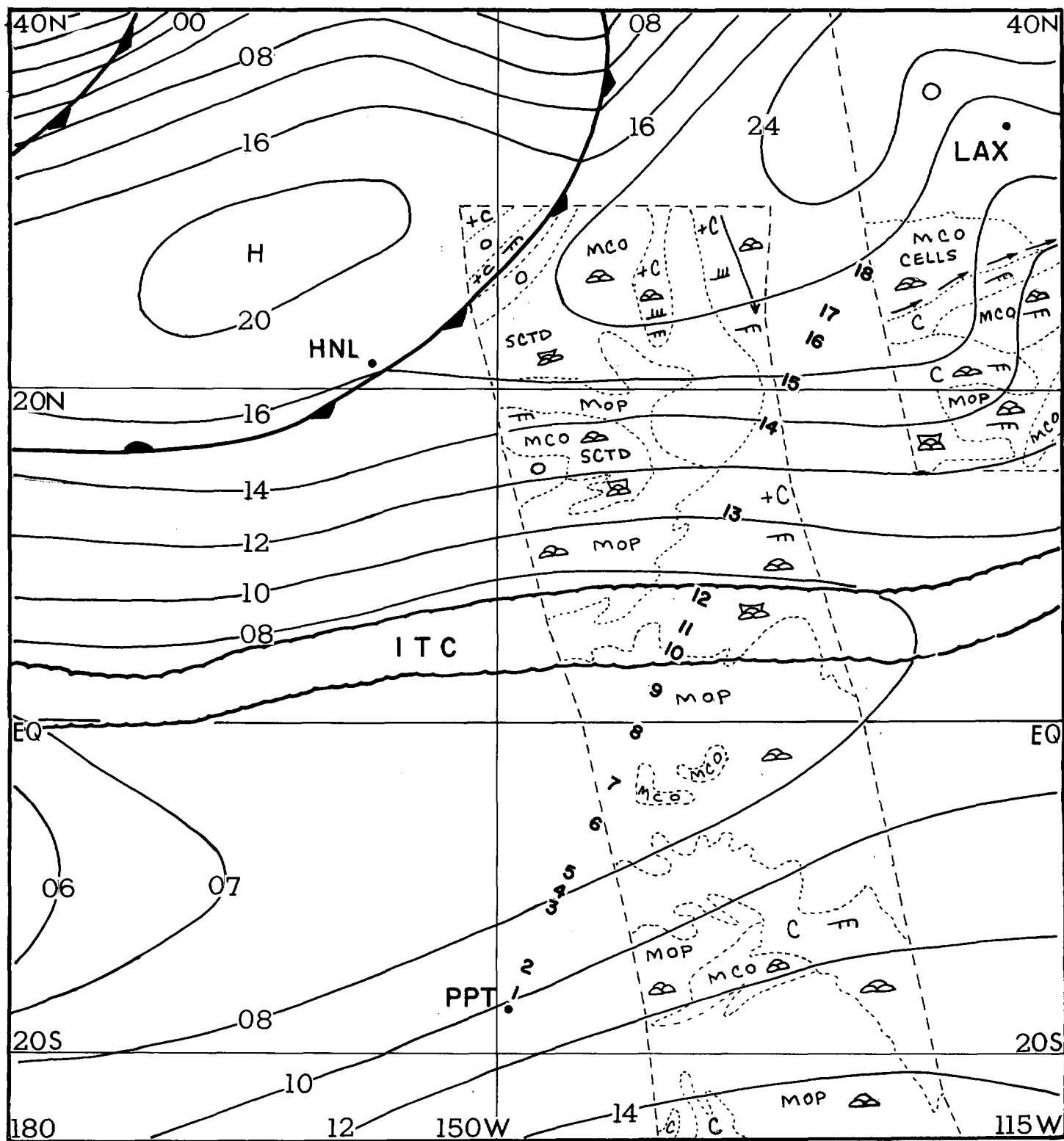


FIGURE 5.—The surface synoptic chart for 0000 GMT January 13, 1966. Isobars are labelled in millibars above 1,000. The intertropical convergence zone is marked ITC. The nephanalyses are those corresponding to the TIROS mosaics of figure 8. The small numbers along a line from Papeete (PPT) to Los Angeles (LAX) correspond to the numbers on the cloud mosaics of figure 8 and the numbered pictures of figure 7.

At 250 mb., however, the flow pattern changed considerably (fig. 6). The sinusoidal trough-ridge pattern in the north Pacific had given way to a more complicated circulation. The northern and southern portions of the trough moved eastward while the central portion rotated into an east-west orientation. An important feature in the south Pacific is the trough across the flight path between Papeete and the equator.

PHOTOGRAPHS FROM AIRCRAFT

The first 12 pictures and the last one on the second leg of the flight were taken pointing toward the WNW. To avoid sunglare, pictures 13 through 17 were taken pointing toward the ESE.

The first three pictures (fig. 7) show undisturbed trade wind skies. The next three are quite different and show clouds characteristic of strong disturbance. There is little in the surface pressure pattern (fig. 5), based on skimpy data, to suggest a disturbance of the low-level circulation. The 250-mb. chart (fig. 6), however, shows that the aircraft was passing through a trough and this is most likely the mechanism for the release of instability. The trough analysis is based both on rawinsonde observations at island stations and on winds observed by our aircraft.

On the northern side of the trough convection was abruptly suppressed, as shown in pictures 7, 8, and 9 (fig. 7). Picture 8, taken within one degree of the equator, shows small cumuli lined up in rows. The scene bears a strong resemblance to the one in picture 10 (fig. 3) also taken over the equator on the southbound leg from Honolulu to Papeete.

Pictures 10, 11, and 12 (fig. 7) were taken within the ITC at an altitude of 35,000 ft. Our notes on picture 10 read, "Seem to be over AS layer which is above Cu. Could AS be from tops of towering Cu?" On picture 11, "No large build-up. ITC?" On picture 12, "No Ci above. Tops estimated 1,000 ft. below flight level. Tops have slight Cu appearance, but what is appearance from below?"

One might expect a sharp clearing after passing through the ITC. But pictures 13, 14, and 15 show little change from the preceding three pictures. The continued convective activity with cloud tops over 30,000 ft. is associated with the upper trough lying across the track just south of 20°N.

The next three pictures (16, 17, 18) show thin stratus clouds. Darkness prevented further photography for the day.

TIROS X PHOTOGRAPHS

The satellite cloud photographs nearest in time to that of the flight were those from TIROS X taken at 1840 GMT (fig. 8B) and 2028 GMT (fig. 8A) January 12, 1966. The later one is the one farther west. The nephanalyses are plotted on the surface chart (fig. 5). The path of the aircraft was at a much greater angle to the satellite's track than it had been on the preceding day. Further, the

TIROS X photographs do not cover the entire track. We cannot, therefore, compare the first six aircraft pictures with the TIROS photographs.

The bands of scattered cumulus clearly shown in pictures 7, 8, and 9 (fig. 7) are also visible at the corresponding spots on the TIROS X photographs (fig. 8) as weak, gray, small streaks. The nephanalyst has characterized this area as "cumuliform, mostly open." Our notes say, "Few cirrus, 2/8, to 3/8 cumulus; cumulus clouds estimated about 1 1/2 mi. in diameter." The sharp change in cloud amount, type, thickness and organization from picture 9 to 10 is also seen in the TIROS X mosaic at spot 10. Spots 10, 11, and 12 are within the zone of the ITC. The features on TIROS X photographs (fig. 8A) at these spots are bright whiteness and a variation in cloud thickness. The nephanalyst described the clouds as cirriform, cumuliform, and cumulus congestus or cumulonimbus.

One of the outstanding characteristics of the ITC, according to Johnson [9], is its distinctness from and contrast with the adjacent zones. However, in this case TIROS X shows that there is hardly any change in cloud brightness, organization, or texture north of spot 12. And one gains the same impression from pictures 13, 14, and 15 (fig. 7). We associate the clouds in these views with inferred upward motion in the sharp 250-mb. trough shown in figure 6. The ITC and the upper trough have combined to produce an area of thick clouds extending more than 1,000 mi. in length. It would have been difficult to anticipate this condition from either the surface or upper air chart alone.

4. FLIGHT FROM LOS ANGELES TO HONOLULU

SYNOPTIC SITUATION

On January 13, 1966, at 2033 GMT we departed Los Angeles on the final leg and landed about 5 hr. later in Honolulu. The flight level was at 28,000 ft. The surface synoptic situation for 0000 GMT January 14, 1966, is shown in figure 9. The entire flight path was in tropical air on the southern side of a High centered near 35°N., 140°W.

At 250 mb. (fig. 10) we see that the trough-ridge system north of 20°N. moved eastward in the past day; the trough near 20°N. on the Papeete-Los Angeles line was transformed into a closed cyclonic circulation, and the trough in the Southern Hemisphere near Papeete persisted without much change.

PHOTOGRAPHS FROM AIRCRAFT

All aircraft pictures on this leg (fig. 11) were taken pointing toward the NNW. Our notes on picture 1, taken just outside Los Angeles read, "Ci, 1/8, some contrails;" on picture 2, "Few Ci; Sc, 3/8, well-defined rows NNW to SSE." The next four pictures show patches of thin stratocumulus with a weak tendency to line up in rows. It is not clear from either the surface or upper air charts why

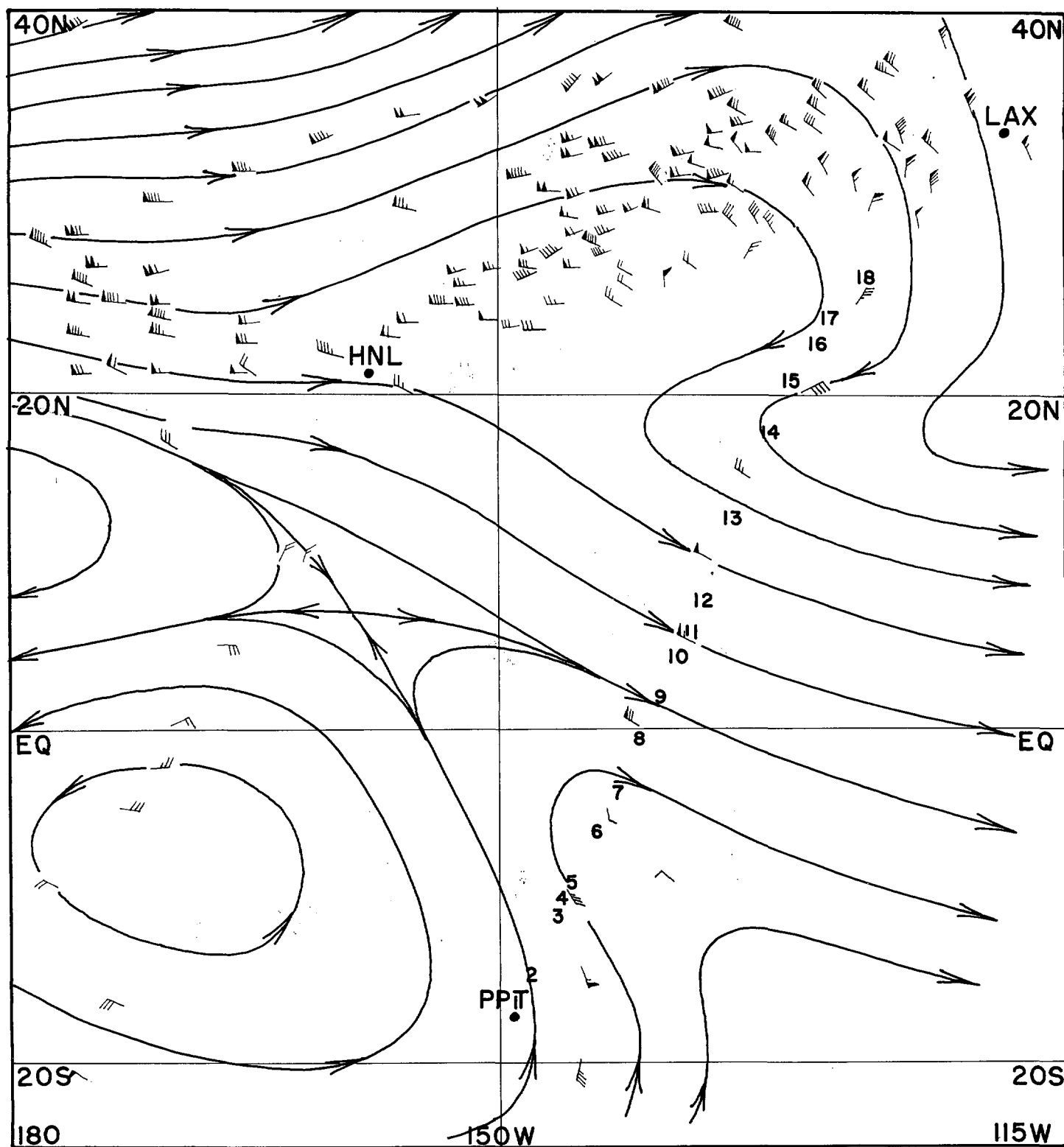


FIGURE 6.—The 250-mb. streamline chart for 0000 GMT January 13, 1966. Symbols as in figure 2.



FIGURE 7.—Enlargements of 35-mm. slides.

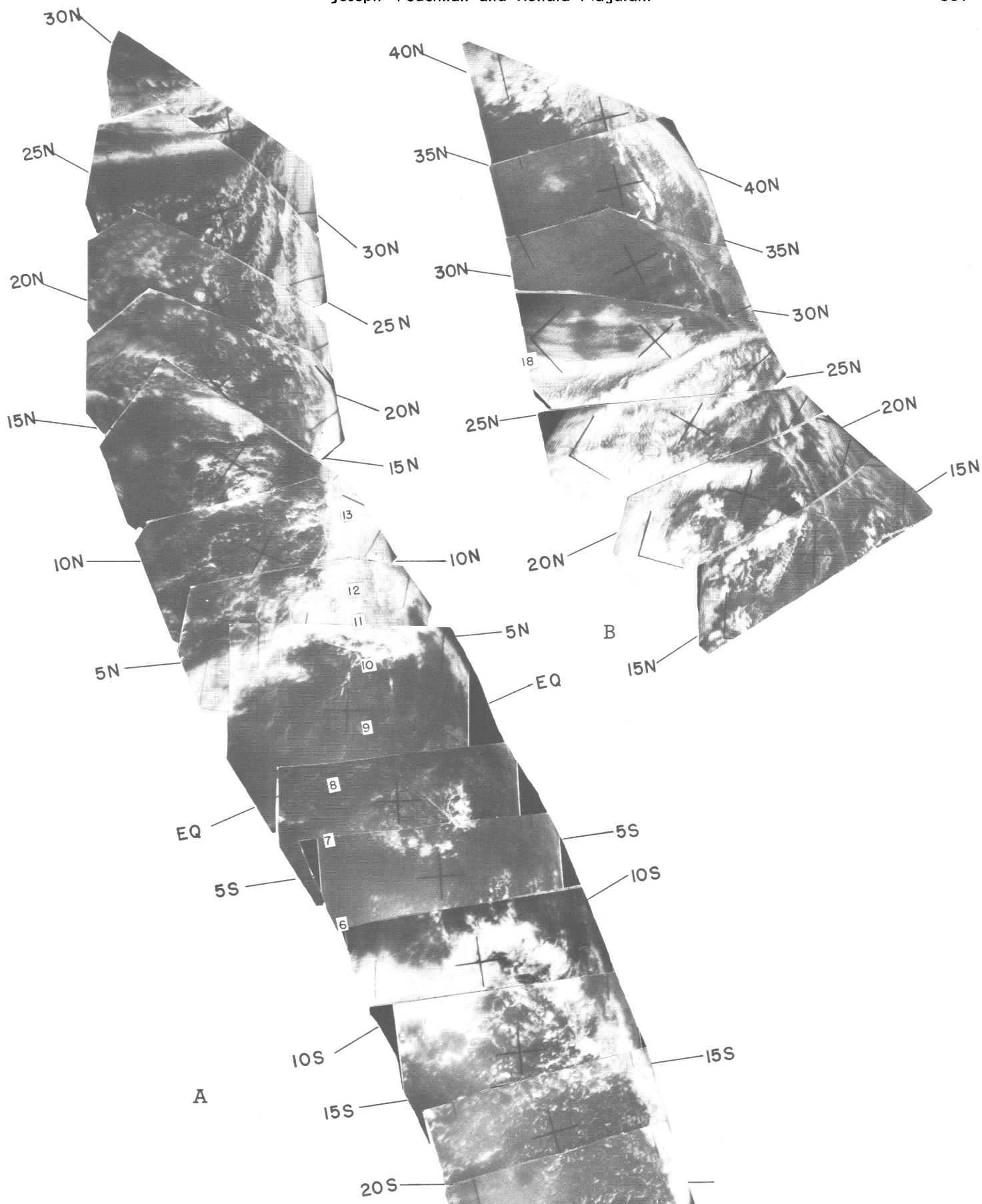


FIGURE 8.—TIROS X mosaics. (A) The western pass is for 2028 GMT January 12, 1966; (B) the eastern pass for 1847 GMT January 12, 1966. The numbers along a line from Papeete to Los Angeles correspond to those on the nephelyses and the pictures.

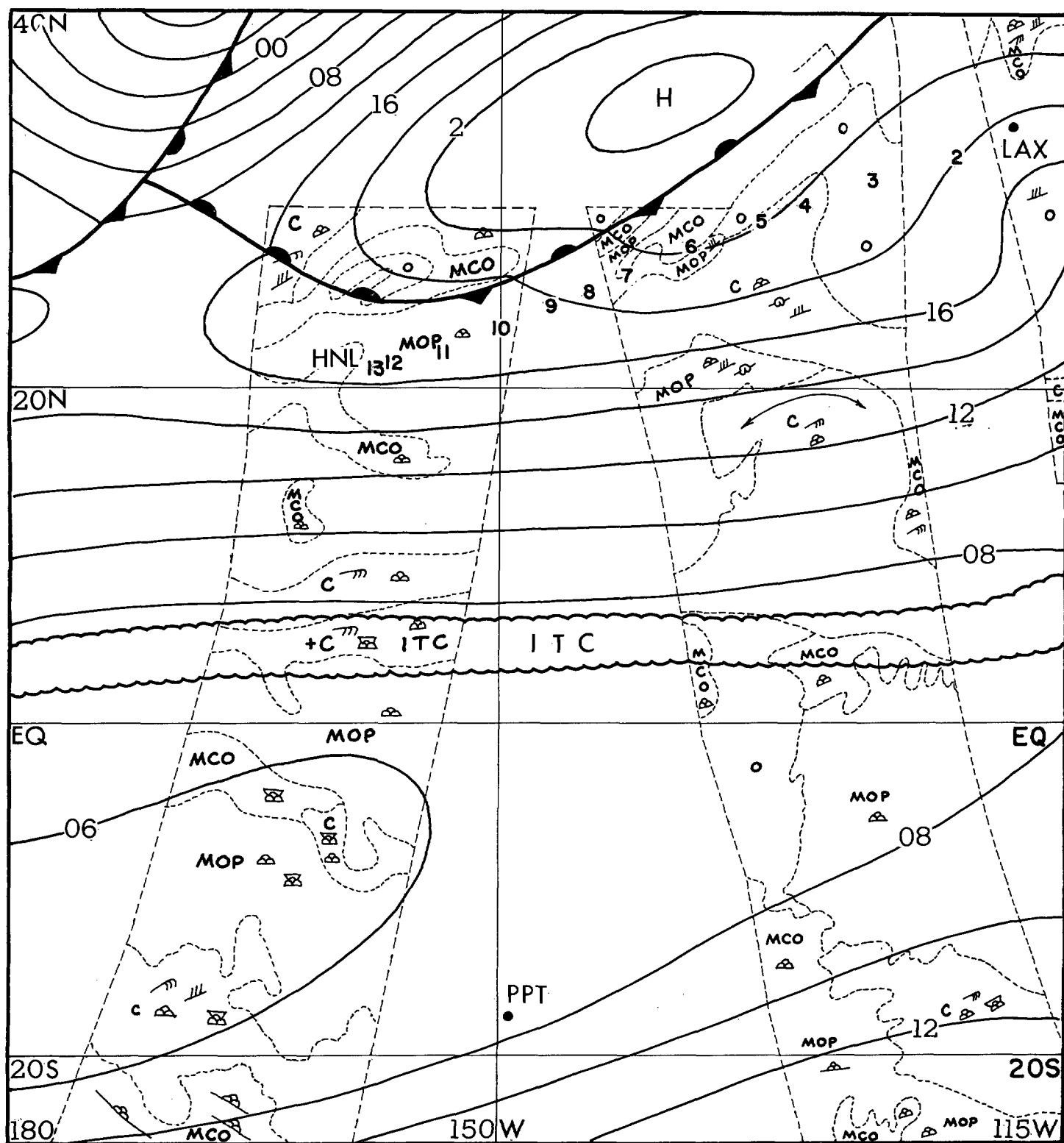


FIGURE 9.—The surface synoptic chart for 0000 GMT January 14, 1966. Isobars are labelled in millibars above 1,000. The intertropical convergence zone is marked ITC. The nephanalyses are those corresponding to the TIROS mosaics of figure 12. The small numbers along a line from Los Angeles (LAX) to Honolulu (HNL) correspond to the numbers on the cloud mosaics of figure 12 and the numbered pictures of figure 11.

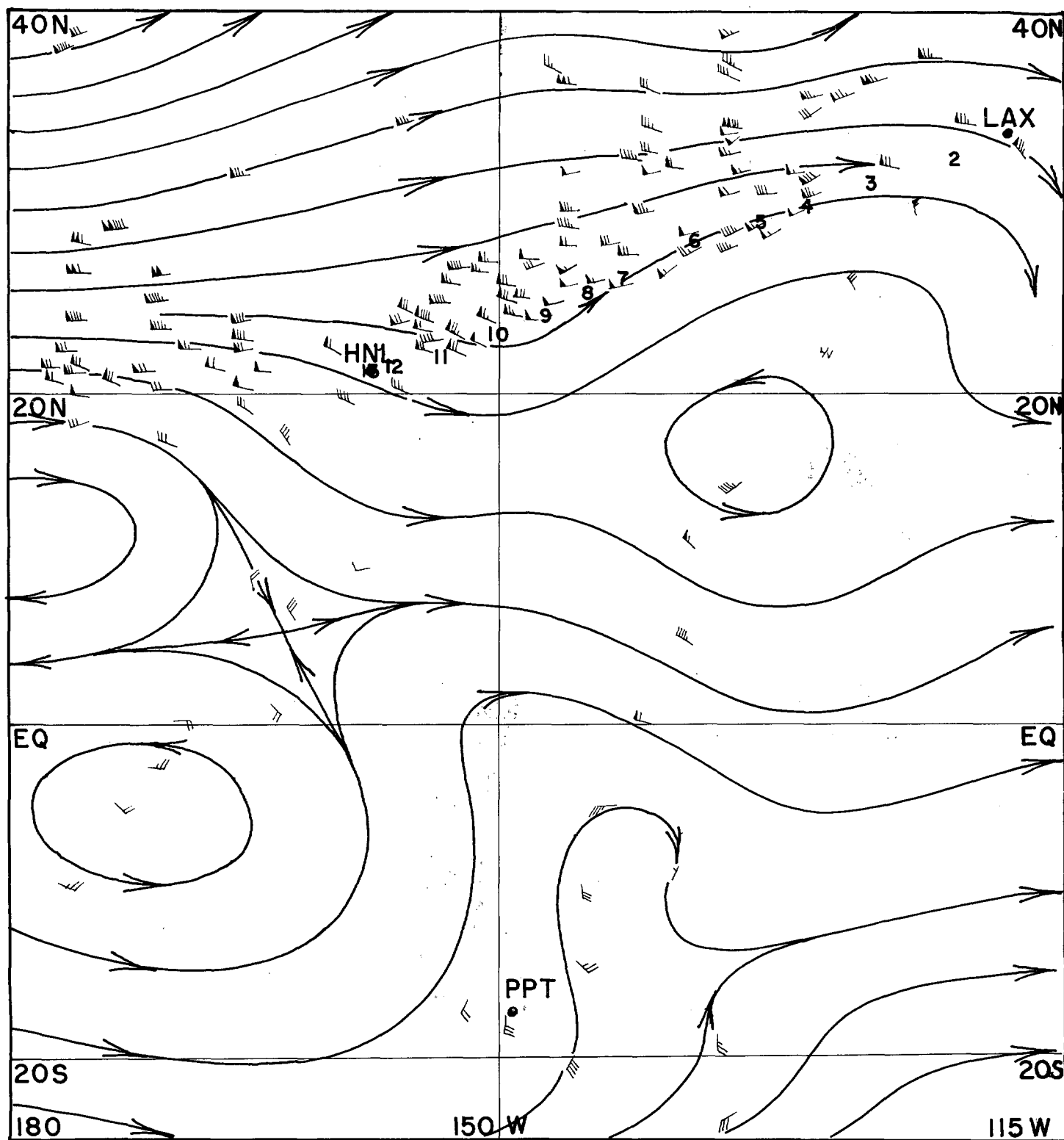


FIGURE 10.—The 250-mb. streamline chart for 0000 GMT January 14, 1966. Symbols as in figure 2.

picture 7 should be so different from those before and after. Picture 7 was described as, "Sc flat tops, 7/8." Our notes refer to a change in cloud types from stratocumulus to cumulus humilis in passing through the area viewed by pictures 8 and 9. The remaining pictures, 10 through 13, show typical undisturbed tropical cumulus.

TIROS IX AND X PHOTOGRAPHS

Three TIROS IX and X passes covered portions of the flight path (fig. 12). The nephanalyses are plotted on the surface chart (fig. 9). The easternmost pass (fig. 12C) shows that the California and Baja California coasts are free of clouds. What one would see from an aircraft at



FIGURE 11.—Enlargements of 35-mm. slides.

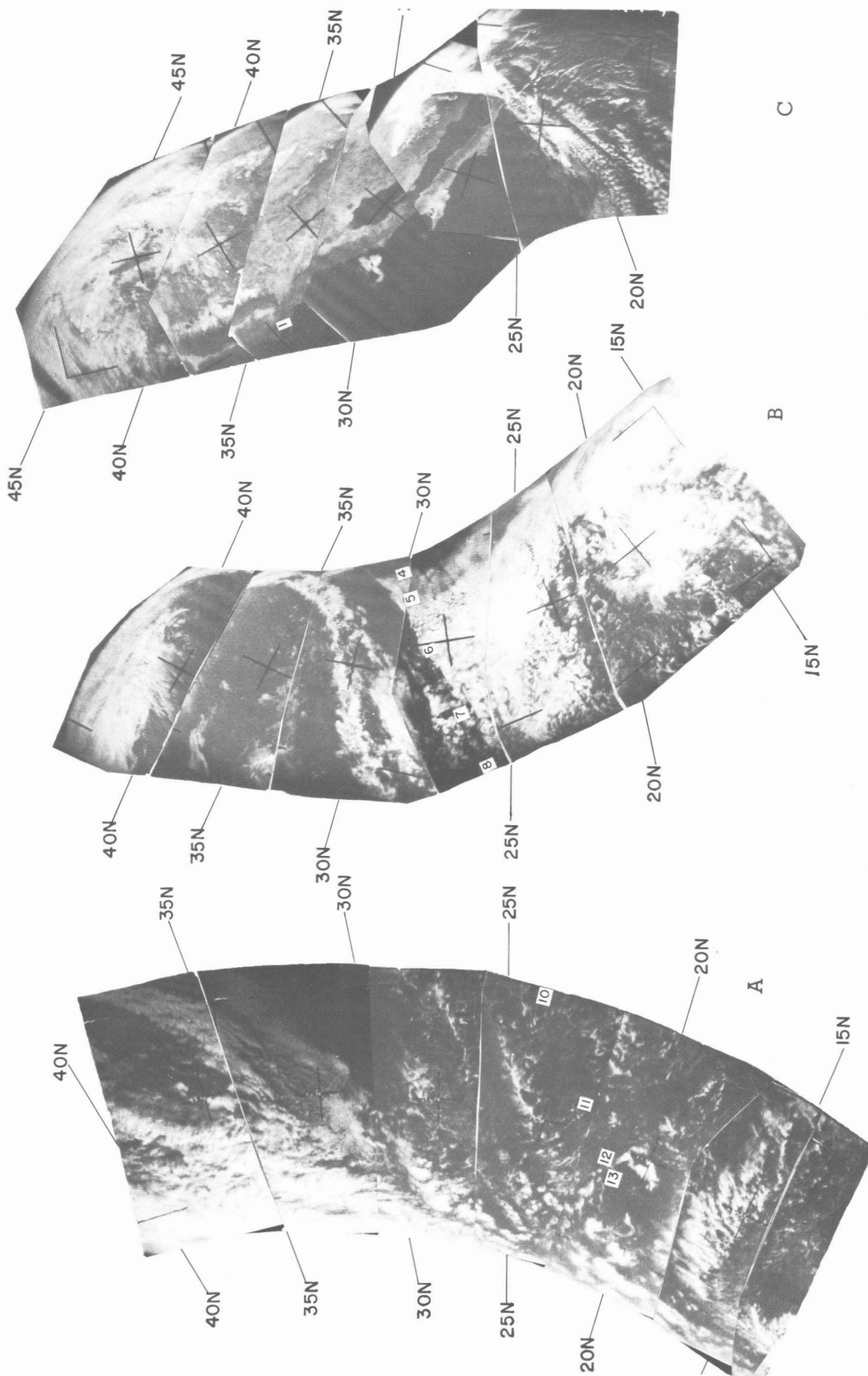


FIGURE 12.—TIROS IX and X mosaics. (A) The westernmost pass is for 0140 gmt January 14, 1966; (B) the central pass for 1958 gmt January 13, 1966; (C) the easternmost pass is for 1819 gmt January 13, 1966. The numbers along a line from Los Angeles to Honolulu correspond to those on the nephalanalyses and the slides.

TIROS spots 4, 5, and 6 would depend largely on what direction one looked since there is a sharp cloud boundary in that neighborhood. The aircraft pictures at those spots were taken looking toward the NNW, where a minimum of cloudiness would be expected from inspection of the central TIROS pass. The greater amount of cloudiness near spot 7 agrees with the corresponding aircraft picture except that, judging from the TIROS picture (fig. 12B), one might have expected to see more convective activity. The sharp change in cloud amount at spots 7 and 8 (fig. 12B) appears to be more than that in the corresponding aircraft pictures. The cloud interpretation at the four spots on the westernmost TIROS pass (fig. 12A) would most likely be "scattered cumulus with little vertical development." And the slides show that this was indeed the case.

5. DISCUSSION

In the present state of science can TIROS satellite cloud pictures be used effectively as a briefing tool for aircrews on long over-ocean flights?

To be used most effectively at field stations TIROS cloud photographs or nephanalyses should (1) be in the hands of the station meteorologists within 2 or 3 hr. of receipt at a read-out installation; (2) completely cover the various flight routes from the station; and (3) contain easily decipherable information about location of storm centers, cloud thickness, cloud tops, turbulence, icing, and existence of cloud layers.

One TIROS pass covered the entire first leg of the trip, Honolulu to Papeete (fig. 4). Passes of this kind are very convenient to use. The two passes across the Papeete to Los Angeles leg failed to cover it very well (fig. 8). TIROS passes over the Los Angeles to Honolulu leg left considerable gaps even though both TIROS IX and X participated in the coverage (fig. 32). It was 7 hr. 21 min. between the eastern and western passes, the scheduled flying time between Los Angeles and Honolulu was 5 hr. 20 min. Since neither of these stations are read-out stations it would ordinarily take an additional 6 to 12 hr. after picture-taking time to deliver the nephanalyses to the field user. It would seem that under these conditions TIROS cloud information would be of operational utility only over areas where little or no other information is available and where the synoptic situation is changing slowly. The Automatic Picture Transmission (APT) system now being carried on later model satellites, such as ESSA IV, delivers within minutes long north-south strips of cloud photographs about 1,500 n. mi. wide. They have received widespread and enthusiastic reception by meteorologists and flight crews. However, it still takes ESSA IV about 10 hr. to photograph the entire Pacific Ocean area. Interchange of APT among such stations as Guam, Wake Island, Honolulu, and San Francisco would

give those stations complete coverage of the Pacific but formidable communication difficulties have prevented this from being realized.

Experiments in APT and cloud photography of the entire Pacific Ocean and portions of the adjacent continents at short time intervals from the stationary satellites ATS-1 over the equator in mid-Pacific are taking place at this time (April 1967). They seem to point the way to large areal coverage and rapid dissemination of information.

TIROS photographs spot storm centers with accuracy. Meteorologists are making good progress in estimating the altitude of cloud tops from the photographs. Much work needs to be done, however, before operationally useful information on turbulence, icing, and cloud layers can be deduced from TIROS photographs.

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